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ABSTRACT

The ability to allocate attentional resources to relevant aspects of a stimulus event is a critical skill needed for efficient information processing. Evidence suggests that this ability to focus on relevant information without interference is dependent on the nature of the stimulus structure of the information to be processed. To test the hypothesis that stimulus structure plays an important role in the processing of multidimensional objects, a speeded classification task designed to measure successful focused attention was employed in a study involving 45 college students. Subjects were asked to sort objects on the basis of their dimensional values. Three dimensional sets were used: fused integral (hue/brightness), analyzable integral (integral color/form), and a newly developed set of objects composed of separable dimensions (separable color/form). The results obtained with fused integral dimensions indicated that processing the objects into their component parts was difficult, resulting in interference. Results obtained with integral analyzable stimuli revealed that subjects were able to process these objects into component parts. Results obtained with the new analyzable stimulus set revealed that subjects experienced no redundancy gains and no interference. Taken collectively, these results suggest that researchers should consider stimulus structure when examining variables which affect the processing of multidimensional objects. (NB)

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Selective Attention with Separable Stimuli Using a Speeded Task

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Selective Attention with Separable Stimuli Using a Speeded Task

The ability to allocate attentional resources to relevant aspects of a stimulus event is a critical skill needed for efficient information processing. Ridding the system of irrelevant information by the efficient use of attentional resources early in processing eliminates the possibility that irrelevant information will interfere with the processing of relevant information. Evidence suggests that the ability to focus on relevant information without interference is dependent on the nature of the stimulus structure of the information to be processed (Garner, 1974; Shepp, 1983).

Gibson (1960) was one of the first to emphasize the importance of looking at how the empirical nature of stimulus information influences the way in which the stimulus is processed. Other investigators have systematically explored the relationship between stimulus structure and subsequent processing (Attneave, 1950; Garner, 1970, 1974; Shepard, 1964). Their work has suggested the need for a distinction between stimulus information that is processed wholistically by the perceptual system and stimulus information that is processed in terms of its component parts. These stimulus structures have been

labeled integral and separable, respectively (Garner, 1970; Lockhead, 1966; Shepard, 1964).

According to Garner (1970), stimuli composed of integral dimensions (e.g., the attributes of color) are such that, in order to realize a value on one dimension of a multidimensional object, values on another dimension must also exist (e.g., hue cannot exist without a brightness). Stimuli composed of separable dimensions (e.g., size of circle and angle of radial line) are such that realizing a value on one dimension is not dependent on the existence of values on any other dimensions. Phenomenologically, objects composed of integral dimensions are perceived wholistically while objects composed of separable dimensions are perceived in terms of their component parts (Lockhead, 1972).

Research employing multidimensional objects in a wide variety of tasks has given rise to need for an extension of the simple integral/separable dichotomy. Some stimuli (e.g., objects composed of the dimensions of color and form - red triangles) have produced results typical of integral stimuli in some tasks and separable stimuli in other tasks. To account for the evidence obtained with this special class of stimuli, Garner (1974, 1976) proposed a continuum of integrality ranging from objects composed of the most integral dimensions (e.g., the attributes of color) to objects composed of the most separable dimensions (e.g., size of circle and angle of radial line).

While a continuum based on stimulus integrality is feasible, other alternatives have been proposed. Shepard (1964) first suggested that the stimuli should be classified in terms of their analyzability. Following Shepard's lead, Shepp (1983) has proposed a continuum of analyzability based on the stimulus dimensions. Analyzability refers to the ability of the perceptual system to break a multidimensional object into its component dimensions and process the components independently. Shepp (1983) provides evidence to suggest that at one end of the continuum of analyzability lie objects composed of dimensions that are fused together (e.g., hue and brightness); for practical purposes these stimuli are not analyzable. At the other end of the continuum lie stimuli composed of dimensions that are distinct objects in and of themselves; these stimuli are highly analyzable. Along the middle of the continuum lie objects composed of dimensions that meet Garner's criterion definition of integral (i.e., in order to realize a value on one dimension, values on another dimension must also exist) but are also analyzable into their component parts (e.g., color and form).

Those objects that are formed by dimensions that are perceptually fused will be referred to as fused integral objects. Those objects that are formed by combining dimensions that are perceptually separate will be referred to as separable objects. Those objects that are formed by

combining integral dimensions that are also analyzable will be referred to as analyzable integral objects.

Operationally, objects formed from these different dimensional combinations show characteristic patterns of results when used in multidimensional scaling, restricted classification, as well as focused and divided attention tasks. In multidimensional scaling tasks, objects composed of fused integral dimensional combinations interact, indicating their dependence on each other when similarity judgments are being made (Burns, McDonough, & Weiner-Ehrlich, 1978; Handel & Imai, 1972; Hyman & Well, 1967). In restricted classification tasks, fused integral dimensions are classified on the basis of overall similarity (Burns, et al., 1978; Smith & Kemler, 1977). When used in focused and divided attention tasks, fused integral dimensions do not allow successful focused attention but do allow successful divided attention (Shepp, 1983).

Objects formed from separable dimensional combinations also show a characteristic pattern of results in scaling, classification, as well as focused and divided attention tasks. The component dimensions are judged independently when subjected to multidimensional scaling tasks. (Burns, et al., 1978; Handel & Imai, 1972; Shepard, 1964). They are put together on the basis of shared dimensional values when employed in a restricted classification task (Burns, et al., 1978; Smith & Kemler, 1977). Furthermore, when used in

focused and divided attention tasks, focused attention is possible but divided attention is not (Shepp, 1983).

Multidimensional objects composed of analyzable integral dimensions behave like objects composed of separable dimensions when subjected to multidimensional scaling tasks; the component dimensions are judged independently (Burns, et al., 1978). When employed in a restricted classification task, analyzable integral dimensions also behave like objects composed of separable dimensions; they are put together on the basis of shared dimensional value (Burns, et al., 1978). However, when used in focused and divided attention tasks these objects behave like objects composed of fused integral dimensions; there is a failure of focused attention and success at divided attention (Shepp, 1983).

Evidence from these tasks suggest that objects composed of dimensions that are fused enter the processing system as wholes and remain intact throughout processing (see also Lockhead, 1972). Thus, when perceivers are asked to make similarity judgments in a multidimensional scaling task they do so on the basis of the component dimensional values. When perceivers are asked to put together fused integral stimuli in a restricted classification task, they do so on the basis of overall similarity because information about the dimensional components of the object is not available. The ability to focus on the value of one dimension to the

exclusion of irrelevant variations of values on the other is difficult with fused dimensional combinations because the perceptual system does not break the object into its parts. For the same reason, dividing resources across the dimensions is an easy perceptual task; the dimensional information remains intact so attending to both dimensions is as easy as attending to a single dimension.

Objects composed of separable dimensions are processed on the basis of their component parts. Each dimension is processed as a distinct object. In the multidimensional scaling task, perceivers make similarity judgments on the basis of the values of each component dimension, thus producing metrics that indicate independence between dimensions. In restricted classification tasks, perceivers put stimuli together on the basis of shared dimensional values, again suggesting that the perceptual system processes the dimensions independently. Furthermore, focused attention is possible with objects composed of separable dimensions; resources can be allocated to one dimension without interference by irrelevant variations of values on the other dimension. However, in order to make decisions about a conjunction of features, the perceptual system must respond to information from both dimensions. Regardless of the analytical (i.e., serial versus parallel) model that is adopted, monitoring two sources of information at a time will take longer than monitoring one,

consequently, making a decision about a conjunction of features takes longer than deciding about either feature alone.

Evidence obtained with objects composed of analyzable integral dimensions suggest that these objects enter the perceptual system as wholes and are later divided into their component parts. Early in processing these stimuli behave like the fused integral stimuli; further processing then makes available information about the component dimensions. When tasks employing analyzable integral objects are speeded (e.g., focused and divided attention tasks) the dimensions that comprise the object remain fused. When the tasks are nonspeeded (e.g., multidimensional scaling and restricted classification tasks) the perceptual system has time to break the object apart and process each dimension independently.

The evidence reviewed thus far indicated that the perceptual system processes objects differently depending on the structure of the stimulus; stimuli composed of fused integral dimensions are processed as wholes, the dimensions that comprise separable stimuli are processed independently, and stimuli composed of analyzable integral dimensions enter as whole objects and are later divided into their component parts (Burns, 1979; Callaghan, 1983).

Not only does the structure of incoming information play a role in the way in which that information is

processed, but it has important implications for the way in which attentional resources can be used in processing. The ability to focus attentional resources on one component of a multidimensional object is, in part, dependent on the structure of that object. If the object is composed of fused integral dimensions, then attending to one dimension is difficult because the dimensions remain fused throughout the processing system. If the object is composed of separable dimensions, then focusing attention on one dimension without interference from irrelevant variations in the other is a relatively simple perceptual task because the dimensions that comprise the objects are objects themselves and can, therefore, be processed independently. If the object is composed of analyzable integral dimensions, then the ability to focus attentional resources on one dimension without interference from the other is dependent on the speed at which decisions must be made. With unlimited time, the perceptual system has a chance to break the object into component parts; consequently, making decisions about a single dimension without interference from the other is possible. The ability to focus on one dimension may be impaired when the task is speeded because the perceptual system has not been given enough time to decompose the object into its parts.

To further test the hypothesis that stimulus structure plays an important role in the processing of

multidimensional objects, a speeded classification task designed to measure successful focused attention was employed. Subjects were asked to sort objects on the basis of their dimensional values. Three dimensional sets were used: fused integral (hue/brightness), analyzable integral (integral color/form), and a newly developed set of objects composed of separable dimensions (separable color/form). Based on previous findings with similar tasks, it is predicted that focused attention should not be possible with the fused integral stimuli. With the analyzable integral stimuli, focused attention should not be possible because of the speed involved in the task. Finally, focused attention should be possible with the separable stimuli.

Method

Subjects.

Forty-five subjects (18 male, 27 female) from the University of Nevada, Las Vegas participated in the study for extra credit. Subjects ranged in age from 18 to 27 (mean = 20.93, sd = 2.39). All subjects had normal or corrected-to-normal vision and reported no color vision problems.

Stimuli.

Hue/Brightness. Stimuli were generated from a two by two stimulus matrix (see Figure 1) of 2.5 cm squares constructed from Panatone Letrafilm Overlay paper by

Letraset; hue values were 172-A (orange) and 185-A (red) and brightness levels, as indicated by tint, were 70% tint and 10% tint. Control hue stimuli were constructed using 50% tint of the two hue values. Control brightness stimuli were constructed using 70% and 10% tint of a neutral Panatone grey overlay (Process Black-2).

Insert Figure 1 about here

Integral Color/Form. Stimuli were generated from a two by two stimulus matrix of triangles and squares constructed from Panatone Letrafilm Overlay paper; hue values were 172-A (orange) and 185-A (red) with brightness held constant at 50% tint. The base of the triangles was 2.5 dm and the height 2.2 cm. The squares were 2.5 cm per side.

Separable Color/Form. Stimuli were generated from a two by two stimulus matrix of squares outlined in red or green ink (2 mm wide) drawn on 5.5 cm by 6 cm white paper with solid black circles or triangles centered in the squares. The squares were 2.5 cm per side. The inlayed circles were 1.1 cm in diameter and the inlayed triangles were 1.5 cm along the base and 1.2 cm in height. Control color stimuli contained no inserted form stimuli and control form stimuli had no surrounding colored square.

The stimuli from all three dimensional sets were mounted on 8 cm by 7 cm matted black paper and then laminated.

The Task.

A speeded sorting task similar to that of Shepp and Swartz (1976) was used. Each subject was asked to sort a deck of 32 cards into two piles. Three types of decks were used. In control decks, the values on one dimension were varied while the values of the second dimension were held constant or not included. In the correlated decks, the values on both dimensions were varied and a specific value on one dimension was consistently paired with a specific value on the other. Thus, the values of the irrelevant dimension was correlated with the values of the relevant dimensions. In the orthogonal decks, the values of both dimensions were varied but both values of one dimensions were paired with both values of the other, resulting in four distinct stimuli (See Figure 1).

Procedure

The subjects were tested individually in an experimental room. Subjects were asked to sort the decks of cards into two piles on the basis of one of the dimensions (e.g., color - red would go in one pile and orange in another). Each subject was asked to sort each of the three decks three times. The order of deck presentation was counterbalanced using a Latin square design. The decks were

shuffled between sorts and subjects were allowed to hold the decks during the sort.

The sorting times were recorded to the nearest millisecond using a digital stopwatch. Errors were recorded but no feedback was given.

Results

Analyses of the sorting times for each dimension, each condition, and each trial for each stimulus set indicated the expected practice effects (trial 3 sorts were significantly faster than trial 1 sorts) however, no trial by dimension or trial by condition effects were found. Consequently, only the third trial data from each stimulus set are presented.

The mean sorting times for all three stimulus sets are shown in Table 1. Each stimulus set was analyzed separately using a two by three within-subjects analysis of variance (ANOVA). The factors were Dimension (hue vs. brightness or integral color vs. form or separable color vs. form), and Condition (control vs. correlated dimensions or control vs. orthogonal dimensions).

Insert Table 1 about here

Hue/Brightness. Results of the ANOVA for the hue/brightness stimulus set indicated no main effect of Dimension ($F(1,14) = .02$, $p > .05$). Hue sorts were

completed as quickly as sorts based on brightness. There was, as predicted, a main effect of Condition ($F(2,28) = 6.16$, $p < .025$). Correlated sorts were faster than control sorts. Furthermore, there was a Condition x Dimension interaction ($F(2,28) = 8.28$, $p < .001$). When sorting on the basis of hue, subjects experienced a redundancy gain (correlated sorts were faster than control sorts) and interference (orthogonal sorts were longer than control sorts). When sorting on the basis of brightness there was a redundancy gain but no interference.

Integral Color/Form. Results of the ANOVA for the integral color/form set indicated no main effect of Dimension ($F(1,14) = .07$, $p > .05$); sorts by color were as quick as sorts by form. No main effect of Condition was found nor was there a Dimension x Condition interaction. Correlated sorts were no faster than control sorts for either dimension, nor were orthogonal sorts slower than control sorts for either dimension.

Separable Color/Form. As with the integral color/form stimulus set, no main effects of Dimension or Condition were found. Nor was there a Dimension x Condition interaction. Mean sorting times for color and form were equivalent. No redundancy gain occurred and no interference was present.

Discussion

The results of the experiment offer further support to the hypothesis that perceived stimulus structure can affect

the processing of multidimensional objects. Results obtained with the fused integral dimensions indicate that processing the objects into their component parts is difficult, resulting in interference (i.e., orthogonal sorts take longer than control sorts). The results are consistent with findings from restricted classification tasks (Burns, et al., 1978; Smith & Kemler, 1977) and focused attention tasks (Shepp, 1983). The failure to obtain interference when brightness was the target dimension is a bit troubling but is not likely a result of being able to analyze the object into its component dimensions; instead, the result appears to be due to the difficulty of sorting neutral grey stimuli on a black background. Consequently, the control sort times were very long, and though interference may have occurred with the red and orange stimuli, it did not produce sorting times longer than the sorts with the neutral grey stimuli. A return to the more commonly used control condition (see Shepp and Swartz, 1976) would likely produce the expected interference effect and offer support for the hypothesis that fused integral stimuli are processed wholistically.

Results obtained with the integral analyzable stimuli did not fit the prediction that a speeded task would prevent dimensional analysis of the stimuli and thus produce a pattern of results similar to that expected with the fused integral stimuli. Instead, subjects were able to process

these objects into their component parts; no redundancy gains were obtained when the dimensions were correlated, nor was there any interference when dimensions varied orthogonally. These findings are consistent with the restricted classification task results previously obtained (Burns, et al., 1978; Handel & Imai, 1972; Shepard, 1964) in which subjects had unlimited time to process the stimuli, and suggest that, when the task allows the subjects to take the time to do the dimensional analyses, they chose to do so.

Results obtained with the new analyzable stimulus set (separable color/form) were as predicted. Subjects experienced no redundancy gains and no interference. The separable dimensions did not fuse to produce a whole object, consequently, correlated sorts were not faster than control sorts. Furthermore, the presence of irrelevant information did not interfere with the processing of the relevant dimensions, suggesting independence in the processing of the dimensions and leading to the conclusion that the dimensions are indeed separate.

Together, these results offer more evidence for the hypothesis that investigators need to consider stimulus structure when attempting to understand the variables affecting the processing of multidimensional objects. The results also suggest that task demands (e.g., speeded versus

nonspeeded) may interact with stimulus structure to influence the processing of multidimensional objects.

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Authors' Notes

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Table 1

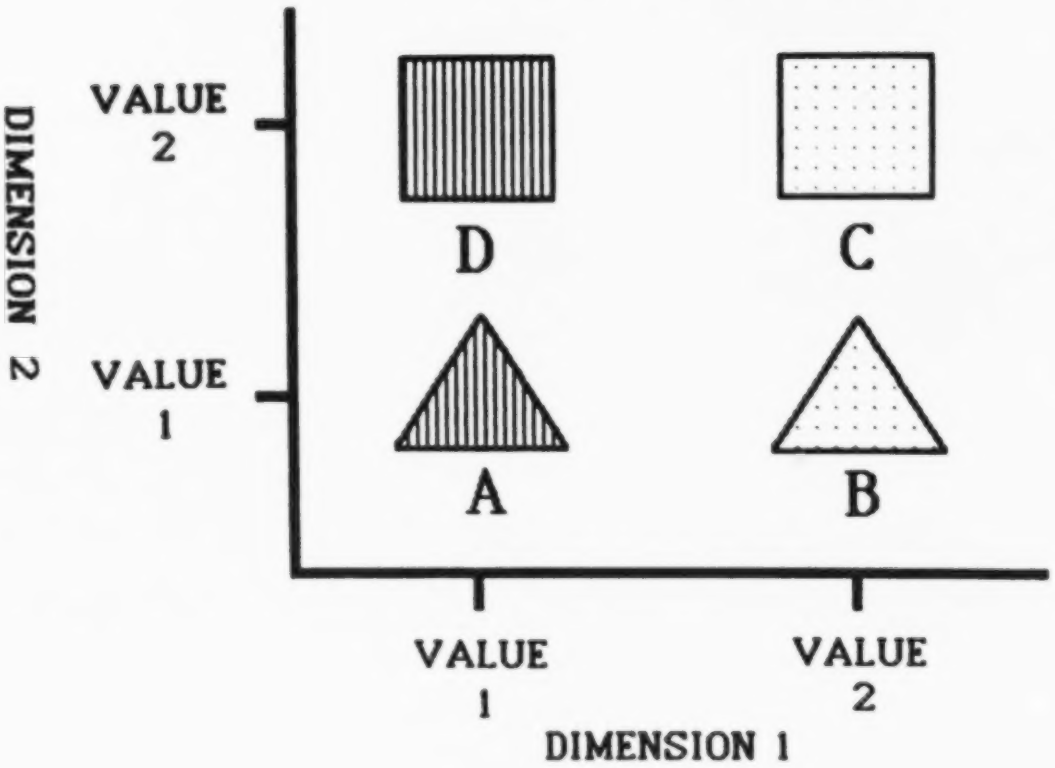
Mean Sorting Times for Control, Correlated, and Orthogonal Conditions for Fused Integral, Analyzable Integral, and Separable Dimensional Sets.

	Condition		
Dimension	Control	Correlated	Orthogonal
Fused Integral			
Hue	16.5	15.9	18.7
Brightness	18.9	15.6	16.5
Analyzable Integral			
Color	15.2	14.4	15.3
Form	14.4	15.4	14.9
Separable			
Color	14.8	14.7	15.9
Form	15.3	15.0	15.8

Figure Captions

Figure 1. Sample two by two matrix used in stimulus construction.

SPEEDED CLASSIFICATION TASK



CONDITION	TARGET DIMENSION	PILE 1	PILE 2
CONTROL	Color	A / D	B / C
	Form	A / B	D / C
CORRELATED	Color	A / D	C / B
	Form	A / D	C / B
ORTHOGONAL	Color	A&D	B&C
	Form	A&B	C&D